Subsumption Robotics

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LONG-TERM GOALS

Through the use of subsumption architectures, low cost, simple robots can be developed to undertake the hazard of moving a submunition or scatterable mine to a disposal area for neutralization. A number of these robots acting in unison can provide an order of magnitude increase in the ability of one Explosive Ordnance Disposal (EOD) technician to clear an area. The scatterable submunitions are small in size, measuring two to five inches in maximum dimension. A two-part technique is being investigated to provide a solution to this problem. The detection of these munitions is the first step in the process. This can be achieved by modifying existing robotic vehicles with a controller, sensor, and detection processing capability. The needs for this capability are being addressed outside of this task. The second step is to provide a small, low cost option for pick-up-carry-away (PUCA) operations for submunition clearance. Figure 1 shows prototype vehicles for the two-part technique. The long-term goal is to extend understanding of artificial intelligence principles in teams of cooperating robots, and applying the results to this real world problem.

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OBJECTIVES

Small autonomous vehicles can be controlled with a data driven task-prioritized architecture based upon subsumptive algorithms. These algorithms are used in robotics to control simple movements and tasks that would otherwise overwhelm a higher architecture controller's processing power. The primary attribute of a subsumptive control is that response and motion behaviors are given to the vehicle and triggered by sensory perceptions in a data driven manner. That is, behaviors are decided based on the application of rules to data collected by sensors. Behavior priorities are used for conflict resolution, such as encountering an object stops motion. Control decision logic is therefore based on a forward chaining search over the rule base, as opposed to a backward chaining goal driven search as favored in most autonomous vehicle applications.

Figure 1. Basic UXO Gathering System (BUGS) Prototype Robots

Four thrusts are needed to develop the small autonomous vehicle concept for EOD use. These are in the area of simulation, controller methodology, sensor technology, and test bed vehicle(s) development. Our objective is to work in each of these areas to develop the technology enablers for a realizable low cost multiple vehicle autonomous robotic system for rapid clearance of submunitions.

APPROACH

It is essential for the gathering platform to detect and grasp the target and navigate to the collection site. The key for the integration of sensor technology and navigation technology, necessary for a successful test bed, is the control technology. A low cost gathering platform must have low cost sensors and navigation. The robust subsumptive control will utilize the sensor and navigation information to carry out the PUCA mission. To ensure a range of technology concepts are explored, in addition to our laboratory efforts, we have contracted with four companies to develop vehicle and control concepts for this project. Foster-Miller, ISX / IS Robotics, Draper Labs, and K^2T were companies selected. After each of these companies developed and demonstrated their concept on a single vehicle, one approach was selected to develop a multiple vehicle prototype system. The most cost-effective way to explore this technology is through the use of a model based graphics simulator. The simulator is used to study the influence of differing conditions such as terrain type and environment, vehicle control logic, sensor

suites, and target types and density. The Naval Postgraduate School (NPS) is developing a physics based model for this task. Each concept (test bed) developed has been modeled, as well as different employment schemes.

WORK COMPLETED

Based upon single vehicle testing, modeling results, and concept definition papers, ISX / IS Robotics was selected to develop a multiple vehicle prototype system for the submunition clearance task. The ISX / IS Robotics team performed four major tasks for this phase; (1) full evaluation and redesign of their Fetch I robot to improve durability, performance, ease of use, and low-cost duplication, (2) production of four Fetch II robots, (3) port and develop new behavioral software for autonomous and supervised autonomous control, and (4) redesign and develop an enhanced operator control unit (OCU) interface. The control strategy used, consistent with the single vehicle concept demonstrated, is a supervised autonomy. Under this control strategy, the robots operate autonomously, but support and submit to a "human-in-the-loop." The autonomous control architecture is subsumptive-based, using IS Robotics' Behavior Programming Development Environment. A separate OCU coordinates the robots to perform clearance operation efficiently and with minimal inter-robot interference. Implicit cooperation among the robots exists, and more sophisticated team interaction mechanisms are under development. The OCU tracks and displays mission progress via graphical user interface.

The government team also designed and developed a multiple robot prototype system. However, the approach taken was to minimize cost, communication, and navigation requirements. Instead of a directable search for UXO targets, this system performs a bounded random search. No OCU is employed, since there is no interaction with the robots once they are deployed. The robots' control architectures are subsumption based, with an added higher level that provides the behavior conflict resolution based upon the state within which the robot is operating. Two robots have been built and operated together thus far. The system design includes, though not yet implemented, means for inter-vehicle communications to allow for both pre-planned and emergent cooperative behaviors.

Both of these prototype systems were demonstrated at NAVEODTECHDIV for user representatives from all four services, as well as NAVEODTECHDIV and Coastal Systems Station (CSS) technologists. Final reports for this project are being prepared.

The computer modeling and simulation of these systems has continued to evolve. Both concurrent and sequential operations using the initial search platform and the directable low-cost autonomous robots have been modeled. Also, different approaches for the clearance mission have been modeled for the instances when the initial search platform is unavailable, but the low-cost robots can cooperate to identify and search/clear high target density areas.

RESULTS

Two prototype, multiple vehicle systems were developed and demonstrated to further the state-of-the-art of applying subsumption control to real world, meaningful applications. One of these is a system of four robots that are coordinated at the highest level through an OCU, and can be directed to search specific locations or regions, while the other is a purely autonomous system of two robots that randomly search a bounded area. Both of these use a subsumptive architecture for the lowest level

control of the individual robots. The subsumptive control by itself can be used to operate a robot in an unstructured environment, but it is very dependent upon the quality and quantity of sensors that feed the controller. Without adequate sensing capability, the robots will not have the information needed to take full advantage of the subsumptive architecture. Also, the subsumption level itself is useful for the low-level control, but there really needs to be a higher-level control that maintains mission goals, and helps drive the arbitration of conflicting behaviors. The basic concepts for a system using these subsumptive-based controllers were demonstrated, though not all planned capabilities were implemented, and there were several hardware problems encountered. This led to a limited demonstration of capability, but the potential for these types of systems is still of interest to the targeted users. An advanced development (6.3) project is starting to build more capable demonstration systems, based upon the research conducted during the past few years on this project.

For the computer modeling effort, a low-resolution system model was used, and simulations were conducted for five scenarios of munitions clusters. First, the AutoRecorm vehicle (for initial search) is simulated alone in two different configurations. The first uses a rectangular spiral search pattern for fast high-speed survey using its video detection / classification scheme. This method requires the vehicle to enter areas of high target concentration. Secondly, to avoid the risk of the first method, the vehicle path is designed to skirt the clusters while the smaller BUGS vehicles enter the areas of risk. Use of BUGS alone is compared to use of AutoRecorm alone and use of both in a cooperative way.

This year, the simulation model has been used to study both approaches outlined above. For each of five different clusters of munitions, the time taken for the BUGS vehicles alone is prohibitive as they move slowly and have a relatively small detection radius. Use of AutoRecorm alone is unsatisfactory since the risk of entering areas of high concentration is too large. Four different algorithms have been developed for motion control of AutoRecorm where the problem is to avoid threat objects, yet retain the global paths of the basic search pattern. It is shown that significant savings in effectiveness are obtained using a combination of the fast high-resolution detection system cooperating with the low resolution/range of the BUGS. A major report on the modeling results is in progress.

IMPACT/APPLICATIONS

Through the use of distributed architecture systems, simple goal oriented tasks can be accomplished by affordable, disposable robotics systems. Working in conjunction with detection information from another source, these small robotic systems can be applied to a wide range of Department of Defense (DOD) missions (EOD, Mine Countermeasures, and environmental remediation). Research work performed at universities and institutions in the areas of control, propulsion, navigation and sensors is becoming ready for development into systems that can support DOD applications.

Currently EOD technicians use the Remote Controlled Transporter (RCT) to pick up or render safe an Improvised Explosive Device. The Program Management Office, Joint Service EOD (PMS, JSEOD) is currently developing the Remote Ordnance Neutralization System (RONS) for use with conventional explosive ordnance. Both RCT and RONS are large, expensive and designed to allow the EOD technician to remotely perform many standard render safe procedures. Use of these systems for clearance of scatterable munitions is not an effective option because of the large size, cost, damage effects of munitions, and slow clearance rate. Disposable, autonomous, mobile robotic systems have many other potential applications. In situations in which repetitive or hazardous tasks must be

performed, these types of systems are attractive. The ability to operate in unstructured environments greatly expands the horizon of possible applications.

TRANSITIONS

This technology is transitioning to the OSD/Joint Robotics Program for EOD applications as the BUGS project. The PMS, JSEOD has scheduled a program in FY01 to begin an Analysis of Alternatives (AoA) study to analyze the BUGS concept for area clearance of small UXO.

RELATED PROJECTS

The work on this project has been reviewed by the CSS, Panama City, as a part of their Surf Zone Technology program. This program investigates the use of small robots to perform clearance of mines and obstacles in the surf zone. The modeling of the robots for the CSS program is leveraging work being performed at NPS.

The Defense Advanced Research Projects Agency (DARPA) has funded small business innovative research efforts with Foster-Miller Corp. (Lemmings) and Rockwell (MITES) to develop small vehicles for explosive neutralization of shallow water mines in the surf-zone. DARPA has recently initiated other programs for small, autonomous robotics. The Small Unit Operations Program focuses on technologies, which enable dispersed military units to perform warfighting operations traditionally accomplished with massed forces. The Tactical Mobile Robotics Program's focus is on perception, autonomous navigation, and locomotion for tactical applications.

The Special Operation Joint Unmanned Systems Cell (SOJUSC) has included this project as a part of its Special Operations Miniature Robotic Vehicles study. SOJUSC's intent is to increase access to denied areas, provide operational standoff, and reduce signatures and operational profiles through the use of small, robotic systems.

Other Navy funded, either in part or wholly, programs include academia work in the locomotion control technologies. We have discussed coordination of this work with Dr. Tom McKenna and visited the sites where his work is performed.

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